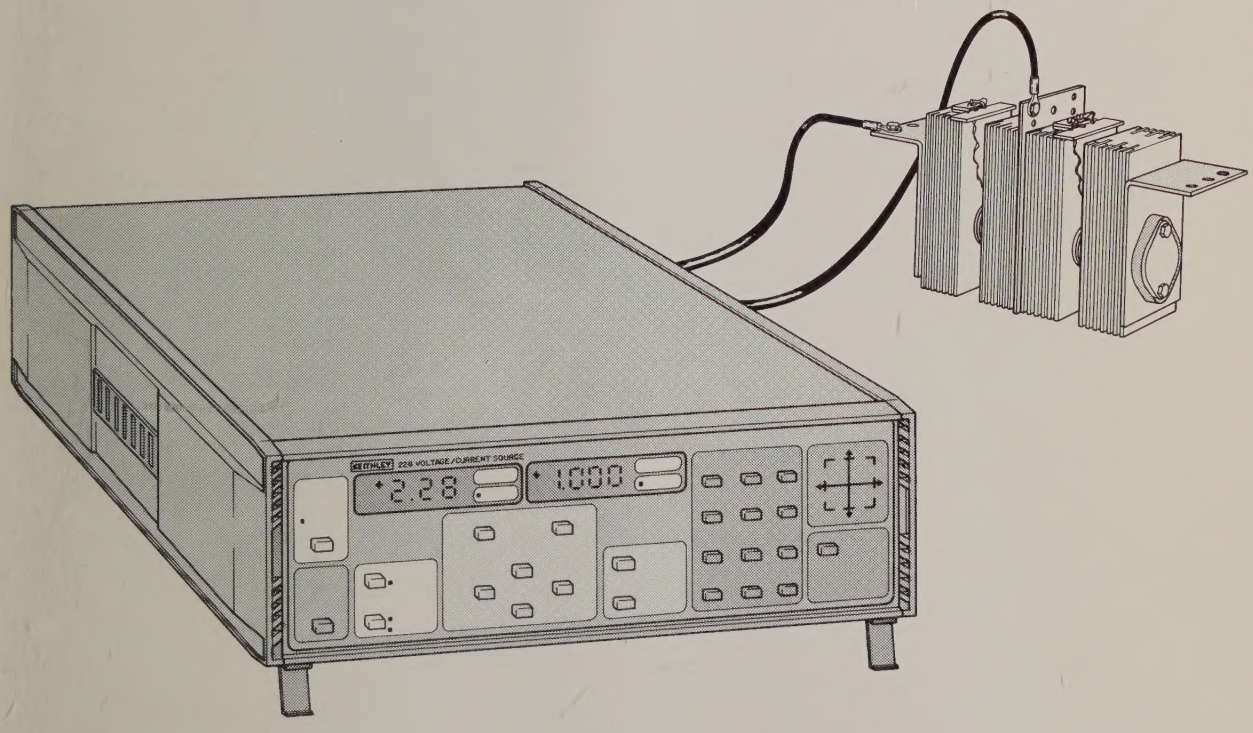
KEITHLEY

Model 228
Voltage/Current Source



Application & Reference Guide

Model 228
Voltage/Current
Source

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Cleveland, Ohio, U.S.A.
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CHAPTER 1

Introduction

This booklet has been written to help the user understand the operation and specifications of the Model 228 Voltage/Current Source. The chapters in this booklet have been written to aid the user in some applications. Terms relating to the V/I source such as: stability, line regulation, load regulation and sensing are defined in the glossary. For a complete explanation of the instrument including front panel controls and IEEE-488 bus operation refer to the Model 228 Instruction Manual (Document Number 228-901-01).

The Model 228 is a power supply that can source or sink electrical power. These unique features set it apart from ordinary power supplies. Actually, because of the Model 228's precision and wide dynamic range, the term SOURCE is used to differentiate it from ordinary power supplies. Most power supplies do what the name implies - they supply power- usually voltage or current. The Model 228 is capable of precise control of voltage or current while sourcing or sinking power.

In general, instruments that are defined as power sources supply electrical power to a connected load. Some power sources can also act as a load for an external source. This is generally known as sinking power. There are numerous applications for an instrument that can sink power as well as supply power. For example, the Model 228 can charge then discharge a battery at a controlled rate.

There are three features that differentiate the Model 228 from power supplies:

1. Multiple Ranges
2. Four Quadrant Operation
3. Constant Voltage/Constant Current

Glossary

Accuracy—Accuracy is defined as how close the actual output value reflects the programmed value. Display monitor accuracy is defined as how close the display monitor reflects the actual output value.

Auto Cal—The A/D converter in the Model 228 measures various gains and offsets within the instrument. With this information, the microprocessor calculates calibration factors which it uses when programming the output. Power on, Program 6 and Program 9 all start the Auto Cal sequence.

Battery Back Up—Values programmed into the 100 step memory are saved even when the AC power is turned off. This is possible because the values are stored in CMOS memory which is powered by a rechargeable battery.

Common Mode Voltage—Common mode voltage is the potential difference between "earth ground and normally common" output terminal of the Model 228. This voltage is normally generated when connecting two power supplies in series.

Compliance—Compliance is defined as the extent to which an output parameter (voltage or current) deviates from the programmed value without compromise of the output parameter. e.g. For constant voltage operation, current control yields to voltage control as long as the actual output current is within the range of $+I_{SETTING}$ (the programmed setting) to $-I_{SETTING}$ (the compliance setting). Outside this range, the current control circuit attempts to take control of the output away from the voltage control circuit.

Constant Voltage/Current—A constant current source can force current through a device under test almost independently of the load resistance. A constant voltage source can deliver a voltage across a device almost independently of the load resistance.

Current Monitor—The Model 228 output current is sensed internally and converted to the ±1V full scale voltage. This voltage is routed to the A/D converter and circuitry but, also is available to the user via the current monitor output terminals.

Dwell Time—Dwell time is the time spent on a specific memory location. Dwell time is used in the Single Step, Single Cycle and Continuous memory control modes. The range of dwell time is 20msec to 1000sec.

Floating—Floating is the term used to describe a condition where a common mode voltage exists between earth ground and the instrument or conductor of interest.

Four Quadrant Operation—In four quadrant operation, voltage or current can be either positive or negative thus, four combinations are possible. Positive polarity of voltage and current is defined as "source quadrants", where power is delivered from the Model 228 to the user's load. Opposite polarity of voltage and current (+V, −I) or (−V, +I) is defined as "sink quadrants", where power from the user is dissipated in the Model 228.

Impedance—The effect of R, L, or C in series or parallel with the output. This causes the output voltage or current to vary slightly when load changes occur.

Load—The device to which power is delivered.

Load Line—The load line is the operating line on the V vs I graph for a particular load.

Load Regulation—Load regulation is the ability of the Model 228 to keep the output voltage or current constant when the load changes.

Modulation (External)—External modulation is a low frequency (DC to 600Hz) low voltage (±10V) signal that is supplied by the user and is superimposed on the output signal of the Model 228.

Operate—Operate programs the output to the user selected values. Standby programs the output to 0V, 0A. During operate, the two displays show actual measured values of voltage and current. During standby, the programmed settings are displayed.

Quick Disconnect Board—An output board that contains the OUTPUT, SENSE, EXTERNAL MODULATION and CURRENT MONITOR terminals. This board fits into the recessed slot on the rear panel of the Model 228.

Response Time—Response time is the time the Model 228 microprocessor takes to respond to a signal on the External Trigger input. Response time is measured from trigger input until the output has change 99% of the difference between the old memory step and the new memory step. A range change, polarity change or change between voltage and current extends the response time.

Self Test—During the power on sequence the Model 228 tests memory (RAM and ROM), the A/D converter control circuitry and power supplies. During operation, the Model 228 monitors temperatures, power supplies and the A/D converter. If an error is discovered, the Model 228 attempts to protect the user and itself.

Sense (Local and Remote)—Remote sensing maintains regulation at the load instead of the output terminals of the Model 228 therefore, compensating for the test leads IR voltage drop. Local sensing maintains regulation at the output terminals of the Model 228.

Source (Vice Sink)—Source is a condition where in the Model 228 delivers power to the user's load.

Stability—Stability is the ability to keep from changing.

Trigger IN & OUT—The TRIGGER IN and TRIGGER OUT connectors are female BNC connectors that accept or output a negative going greater than 10μsec TTL pulse. The trigger input pulse starts the memory control mode. The trigger output pulse appears at the TRIGGER OUT connector at the end of each programmed dwell time.

Standby (Vice Operate)—The standby mode programs the Model 228 to output 0V, 0A and displays the programmed settings instead of the actual values. Polarity and range changes are delayed until the OPERATE button is pressed. Modulation is disabled in the standby mode.

Sink (Vice Source)—Sink is described as the ability of the Model 228 to dissipate power supplied by the user's circuit. This includes discharging batteries, inductive loads and capacitive loads.

Sink Only—Sink only reduces internal dissipation so that a full 100W can be dissipated by the Model 228 for long periods of time, even at high ambient temperatures, with no derating. Since this function reduces the Model 228's sourcing capability ($\approx$1.5A) it should only be used when sourcing is not required.

CHAPTER 2

Safety Precautions

The following information outlines general safety precautions that should be observed before, during and after operating the Model 228.

1. Before operation, ground the Model 228 through a properly earth grounded receptacle. Failure to ground the instrument may result in severe injury or death in the event of a short circuit or malfunction.
2. Never assume the output is at a safe potential while the AC line is connected.
3. Never come into contact with the output connections while the instrument is turned on.
4. Always set up the test circuit while power is turned off. Do not come into contact with any part of the test circuit while power is on.
5. Always place the instrument in standby after the measurement or test is complete.
6. Use cables for the output that have appropriate current and insulation rating. For example, if 10V at 10A is to be produced, or dissipated, then the cables must be rated for that amount. Also, use insulated lugs for connections on the quick disconnect board.
7. The Model 228 is capable of producing several times its current rating for short periods of time. Keep this in mind when choosing a load. Brief bursts of high current are still enough to damage other instrumentation and cause serious injury.
8. Do not operate the Model 228 with the top and/or bottom covers removed. Lethal potentials are present throughout the mainframe. The covers must also be in place to allow proper air flow through the instrument. Proper air flow is required to cool the instrument during operation. If proper cooling is impeded the instrument may overheat.
9. When connecting active circuits, observe proper polarity (sink mode). A reversed polarity may allow the instrument to operate at the current limit of the output fuse (20A).
10. When using the Model 228 to sink power from an external source refer to the example program and Program 2 (Sink) in Section 3 of the Model 228 Instruction Manual.
11. The MODULATION – and the I MONITOR – terminals on the quick disconnect board are electrically shorted.
12. The OUT – terminal is at a potential similar to the MODULATION and I MONITOR terminals. Shorting the OUT terminal to the MODULATION and/or I MONITOR terminals shorts the Model 228's current limiting circuitry. The current limiting circuitry will not function properly if the terminals are shorted. Grounded equipment can cause this problem.

    Example: A grounded function generator connected to the modulation input of the Model 228 with a grounded oscilloscope connected across the output terminals of the Model 228.
13. When using multiple Model 228's do not connect the modulation inputs together or the current monitor outputs. Remember, that the OUT – terminals and these other terminals are at similar potentials.

CHAPTER 3

Operating Considerations

General Specifications

For detailed Model 228 specifications refer to the instruction manual. Specifications precede the Table of Contents.

Output & Compliance Accuracy

Accuracy is defined as the degree of uncertainty of a measure to a standard or true value. There are two accuracy specifications to take into consideration when using the Model 228: compliance accuracy and output accuracy. These two specifications are described in the following paragraphs.

Output accuracy refers to the programmed parameters of the Model 228. The programmed parameters are the values set for voltage and current. These values are set by the user either by the use of front panel controls or over the IEEE-488 bus. Output accuracy is in effect when the load does not cause the output to exceed the values of voltage and current set by the user. For example, if the Model 228 is set for 5V, 1A, a resistive load of 10Ω draws 100mA from the Model 228. In the operate mode, the front panel display monitor shows 5.00V and .100A. In this case the programmed parameters were not exceeded. Therefore, the output accuracy is in effect.

Compliance accuracy is in effect when the Model 228 is in the sink mode. The sink mode occurs whenever the monitored voltage and current are of opposite polarity. For example, if the Model 228 is set for 5V, 1A a 10V battery connected to the output terminals (OUT+ connected to the positive of the battery, OUT− connected to the negative of the battery) forces the output of the Model 228 to +10V, −1A. In this example the compliance accuracy becomes effective on current. If the battery is connected across the output terminals with reverse polarity (OUT+ connected to negative of battery, OUT− connected to positive of battery) the Model 228 would be in voltage limit instead of current limit.

CAUTION

Observe proper polarity when connecting active circuits such as batteries and power supplies to the Model 228.

The stated accuracy specifications for output accuracy and compliance accuracy pertain to the source mode and sink mode respectively. The output accuracy applies while sourcing power from the Model 228. The compliance accuracy applies while sinking power to the Model 228.

Display Monitor Accuracy

Accuracy refers to the output of the Model 228. The output value could differ from the programmed value by the specified accuracy. The displayed value could differ from the output value by the specified accuracy.

The displayed readback of the output is approximately 2½ times per second. The programmed output is fast but has some inherent offset. For steady output the display value is more accurate than the programmed setting. For changing output, the programmed setting is precise while the displayed value requires sufficient time to assure steady state.

For example, if the output is programmed for 1.000V with no load, the output will be 1.000V ±2mV. If the output is 1.000V, the display will read 1.000 ±2mV.

Times

Programming time is stated as 30msec maximum from trigger to 99% of programmed change. For example, if 15V is present at the output and the instrument is programmed for 50V, it will take the Model 228 30msec to reach 49.6V. This specification applies when on the same range, and polarity. Time is measured from external input to settled output.

Load transient recovery time is specified with a resistive load only. With a resistive load, the output can recover 90% of any load changes within 1msec after the end of the changes. This time is specified for the changes which do not cause transfer to another control mode. (i.e. voltage to current limit, or source to sink).

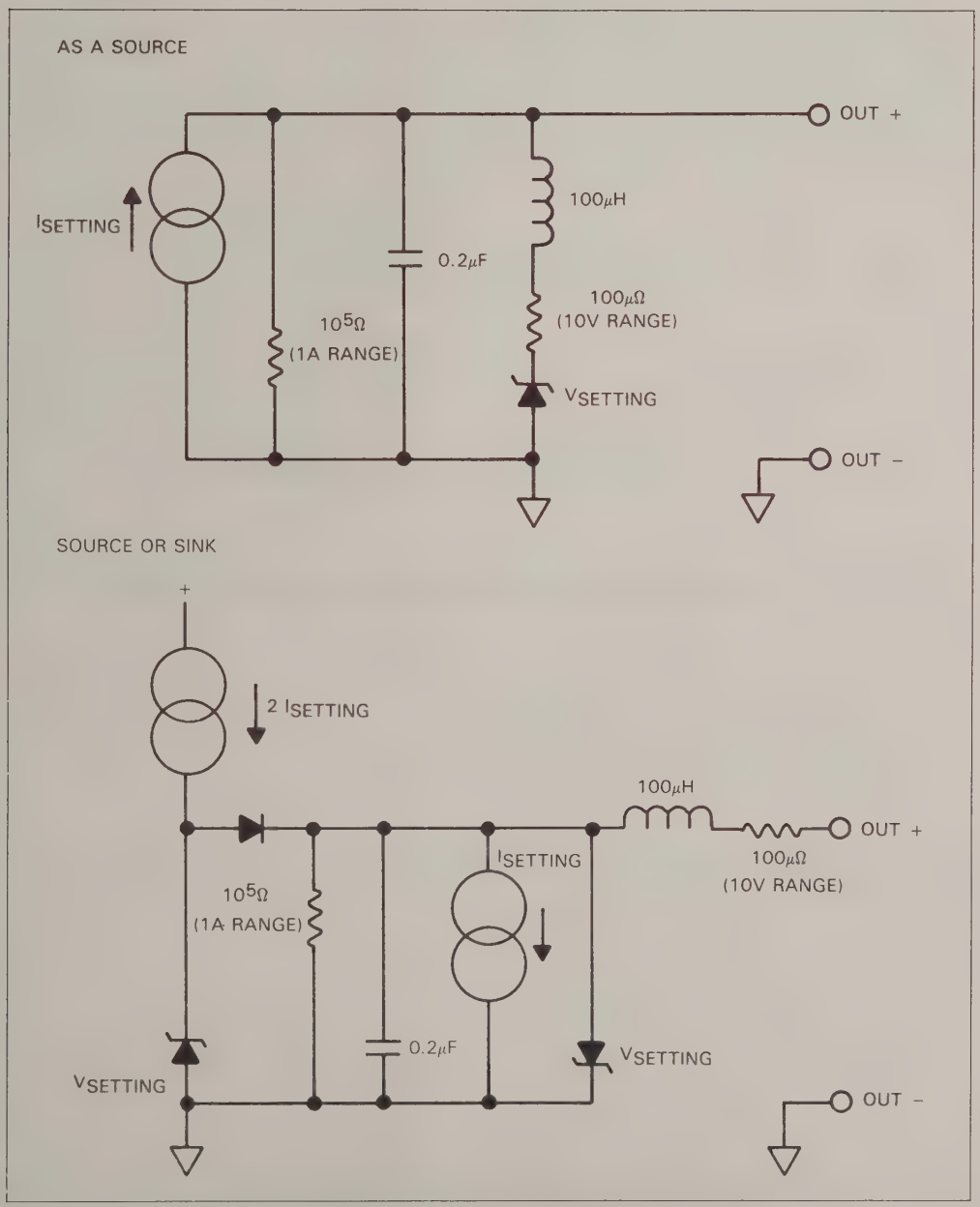


Figure 1. Model 228 Equivalent Output Circuit

The Model 228 is a constant current voltage/constant current source. The load determines the mode of the Model 228, either constant voltage or constant current. For example, if the load is of high impedance, the Model 228 is in the constant voltage mode with the load resistance determining the current mode. If the load is of low impedance, the Model 228 is in the constant current mode with the load resistor determining the voltage. For example, if the Model 228 is programmed to 10V and 10A, a load of more than 1Ω controls the current. A load of less than 1Ω controls the voltage.

$I = 10V/2\Omega = 5A$ (2Ω load, requires 5A)
$V = 10A \times 0.5\Omega = 5V$ (0.5Ω load, requires 5A)

The preceding paragraph can be summarized as follows:

$$R > \frac{V_{228} \text{ setting}}{I_{228} \text{ setting}}$$ then, the Model 228 operates as a constant voltage source.

$$R < \frac{V_{228} \text{setting}}{I_{228} \text{ setting}}$$ then, the Model 228 operates as a constant current source.

Where:
V = The voltage setting on the Model 228.
I = The current setting on the Model 228.
R = Connected load.

Figure 2 shows the Model 228 using a resistive load line. Figure 3 shows the general graph of operation for the Model 228.

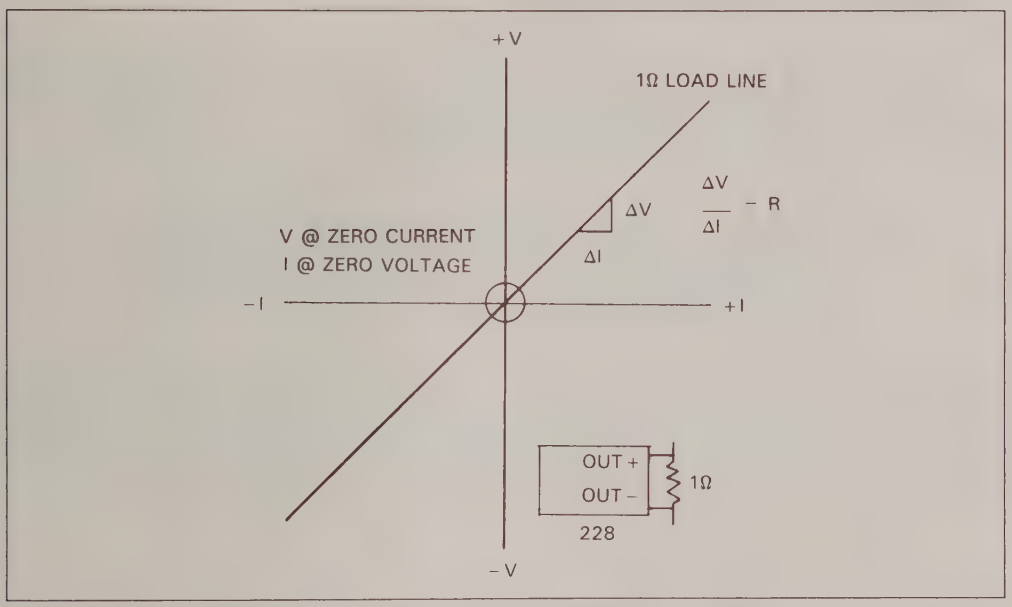
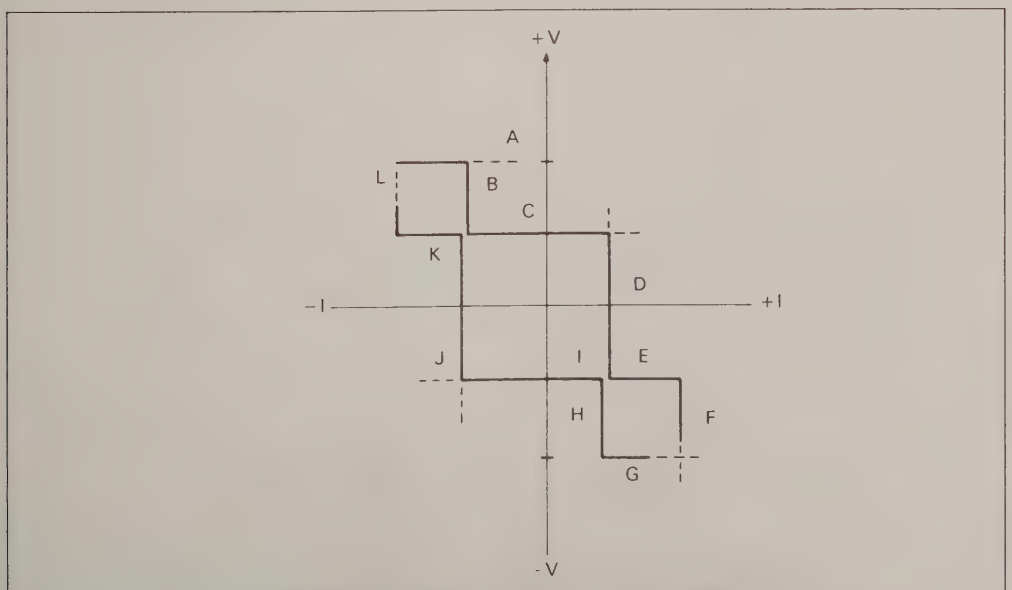


Figure 2. Model 228 with Resistive Load Line



A = +115V (DESTRUCTIVE LIMIT)
B = −CURRENT LIMIT (+PROGRAMMED)
C = +VOLTAGE LIMIT (+PROGRAMMED)
D = +CURRENT LIMIT (+PROGRAMMED)
E = −VOLTAGE LIMIT (+PROGRAMMED)
F = 20A FUSE
G = −115 (DESTRUCTIVE LIMIT)
H = +CURRENT LIMIT (−PROGRAMMED)
I = −VOLTAGE LIMIT (−PROGRAMMED)
J = −CURRENT LIMIT (−PROGRAMMED)
K = +VOLTAGE LIMIT (−PROGRAMMED)
L = 20A FUSE

Figure 3. Graph of Operation

Sensing (Remote and Local)

The sense (S+ and S−) terminals are located on the quick disconnect board. The sense terminals are used in the volts mode. When a load is connected to the Model 228, there is an IR lead drop between the load and the Model 228.

CAUTION

Take care to connect the sense terminals (S+ and S−) to the load with proper polarity. Connect S+ to the positive terminal and S− to the negative terminal. Improper polarity may result in damage to the instrument and load.

The effects of sense current should be taken into consideration when making extremely sensitive tests. The sense current is small but it can still affect the potential that is delivered to the load. To minimize the effects of the sense lead current, keep the resistance of the output leads and sense leads low. Sense current is typically less than 100μA (see Figure 4).

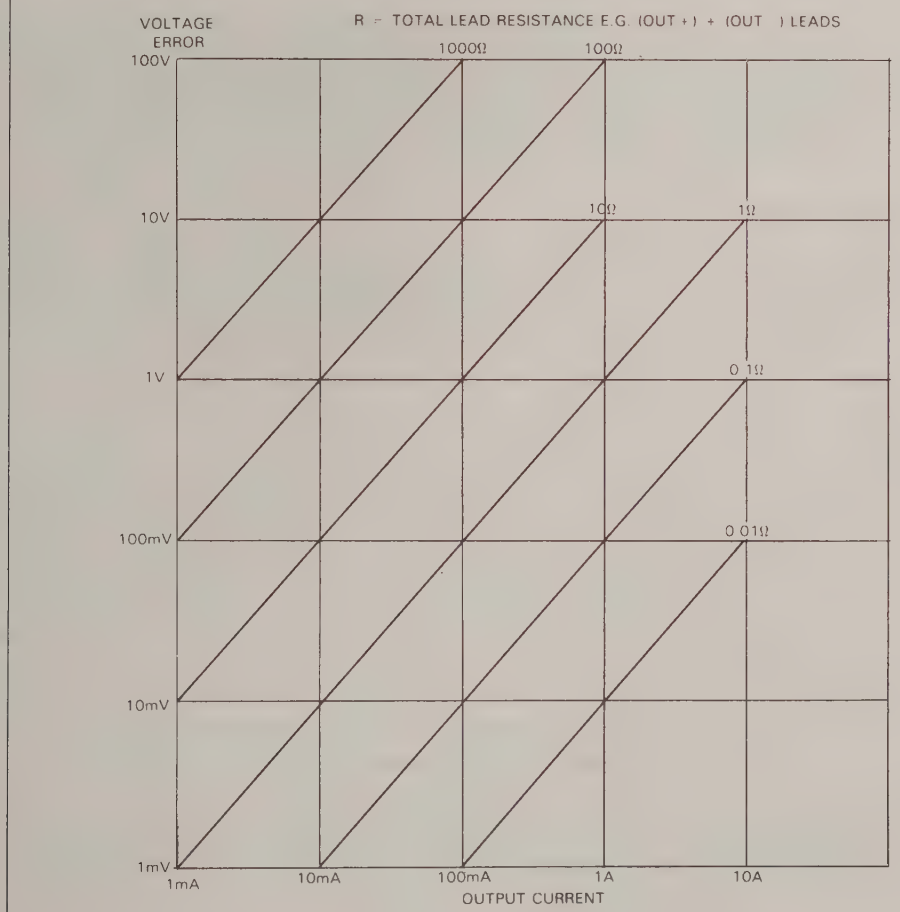


Figure 4. Voltage Error Using Local Sensing

Load Regulation

(Also See Output Impedance)

Load regulation is the ability of the Model 228 to keep the output voltage or current constant when the load changes. Output resistance affects the final (or steady state) value of the ouptut for different loads. Output impedance affects the amount of overshoot, undershoot and settling time (or dynamic response) for a changing load. The Model 228's load regulation can be calculated using the following two methods:

1. As a Current Source

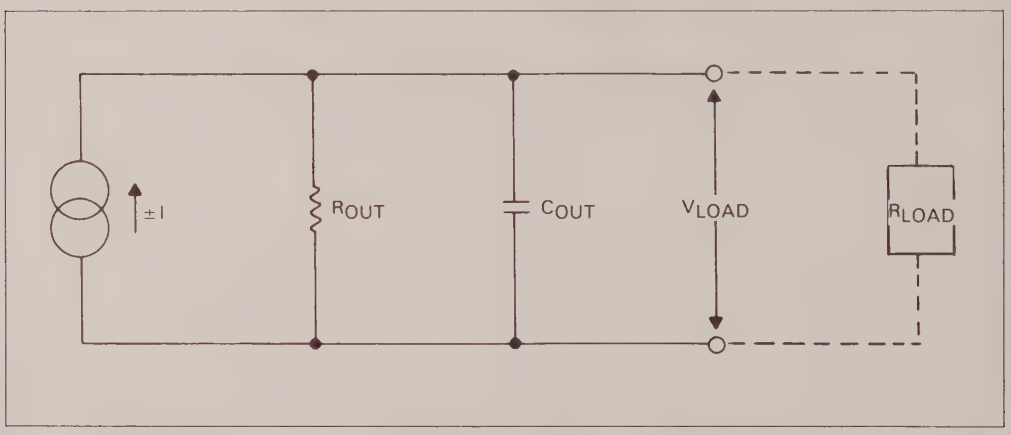


Figure 5. Model 228 as a Current Source

R_{OUT} + C_{OUT} make up the output impedance
Static load regulation: ΔI_{OUT} for different loads

$$= \frac{\Delta V_{OUT} \text{ caused by different loads}}{R_{OUT}}$$

For example: 1A, 100V range current regulation for no load to full load:

$$\Delta I_{OUT} = \frac{\text{Full load}}{100k\Omega} - \frac{\text{No load}}{100k\Omega} = \frac{100V\text{-}0V}{100k\Omega} = 1mA$$

The change in the load is 100Ω to 0Ω.

$$\text{as a \%, } \frac{\Delta I_{OUT}}{I_{OUT}} \times 100\% = \frac{1mA}{1A} \times 100\% = 0.1\%$$

2. As a Voltage Source

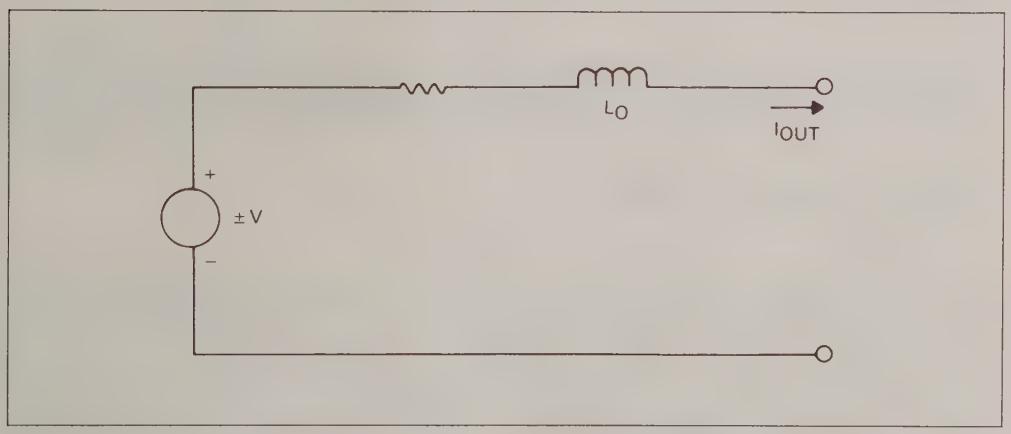


Figure 6. Model 228 as a Voltage Source

$R_O + L_O$ make up the output impedance
Static load regulation: ΔV_{OUT} for different loads =
(ΔI_{OUT} caused by different I_{LOADS}) × (R_O).

For example: 100V, 1A range voltage regulation for no load to full load:
$\Delta V_{OUT} = (1A - 0A) \times (0.010\Omega) = 0.010V$

$$\text{as a \%, } \frac{\Delta V_{OUT}}{V_{OUT}} \times 100\% = \frac{0.010V}{100V} \times 100\% = 0.01\%.$$

Stability

Stability is the ability to maintain consistancy. Factors which affect Model 228 stability include the following parameters:

- Warm Up Time
- Temperature Coefficient
- Power Coefficient
- Auto Cal
- Time
- Output Impedance/Load

Warm up time is the time it takes for the Model 228's internal parts to reach a stable operating temperature. The Model 228 is 100% functional shortly after power on. However, accuracy and stability are not specified until after the temperature has stabilized (10 minutes for rated accuracy).

Temperature coefficient is the additional uncertainty of the output and readback values caused by operating at ambient temperatures outside the normal 18°C-28°C range. For example: What is the expected accuracy of the 10V range at 35°C ambient temperature?
Additional uncertainty = 0.1/°C × (0.1% + 0.1V) × (35°C − 28°C) = 0.07% + 0.07V.
Accuracy ≒ (0 −1% + 0−1V) + (0.07% + 0.07V) = 0.17% + 0.17V.

Auto calibration is performed during the power up sequence. Calibration constants may change by 0.5 counts between auto calibrations. The previous calibration constants may be used by pressing CANCEL while the Model 228 is displaying ''CAL nn''.

External Current Monitor

The current monitor can be used to obtain a faster and more accurate reading from the Model 228 than the front panel display. A voltage level that is proportional to the current level can be monitored using the current monitor output. All current ranges output 1V at full scale (full scale is 100% of range). The accuracy of the current monitor is the same as the constant current mode. The current monitor is not connected to the 3½ digit A/D converter and therefore, has a higher resolution than the front panel display. Current monitor readings may be read back over the IEEE-488 bus, eliminating the need for external metering.

The bandwidth of the current monitor is 5kHz (typical). The output resistance of the current monitor is 10kΩ. The current monitor terminals are located on the quick disconnect board.

NOTE
The current monitor floats at output LO (OUT−).

CHAPTER 4

Applications

The following applications show how the Model 228 could be used in several situations including: Making low resistance measurements, conducting battery tests, semiconductor testing and power supply testing.

Semiconductor Testing

The Model 228 is suitable for testing many of the parameters of power semiconductors such as VMOS FETs, diodes and bipolar transistors. Typical curves for the transistors can be obtained using one or two Model 228s. The Model 228 supplies up to 100W of power for these applications.

Precautions

The current (voltage) limiting of the Model 228 is not instantaneous. The output capacitance (inductance) allows a brief current (voltage) surge before the current (voltage) limiting circuitry reacts. There are two methods for dealing with this situation. The first method is to simply start the measurement with zero current and gradually increase the current to the desired level. This method is very simple and requires no additional circuitry. The second method involves some external circuitry. A resistor in series with the output (zener diode across the output) could be used as a high speed current (voltage) limit if these components have a sufficient power rating. Changing the 20A output fuse to a lower value also helps to protect the user's circuitry.

The Model 228 is not a high speed pulse generator. The fastest pulse that can be programmed into the Model 228 is 20msec. Secondary breakdown characteristics of semiconductors are normally specified in the range of microseconds. Thus, 20msec would be sufficient to destroy the device under test instead of testing the particular parameter.

Obtaining curves for bipolar transistors can be done using two Model 228 sources. One source is connected between the base and emitter and the other source is connected between the collector and the emitter. Figure 7 shows the configuration for obtaining the family of curves for a 2N3055 power transistor. The curves shown represent the collector-emitter voltage versus collector current (V_{CE}/I_C curves).

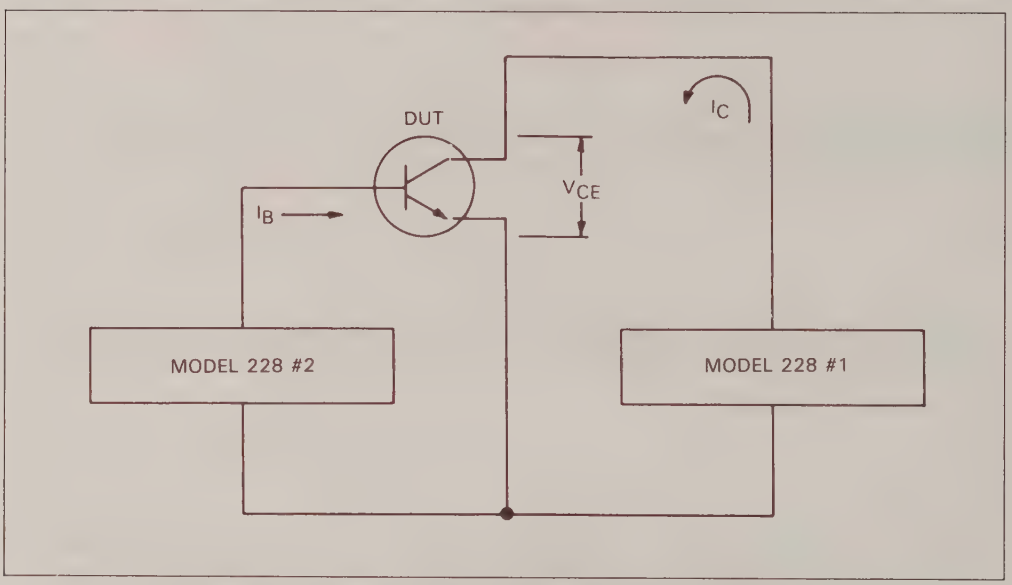


Figure 7. Power Transistor Test Set Up (2N3055)

The Model 228 is capable of producing 100W of power. The power rating of the 2N3055 transistor is approximately 100W. Therefore, the Model 228 is ideal for testing such a widely used power transistor. Refer to Figure 8 for V_{CE}/I_C curves for the 2N3055.

Most V_{CE}/I_C curves illustrated in data manuals show the maximum safe forward bias area. This area is self explanatory and should not be exceeded. Figure 8 shows a typical structure of V_{CE}/I_C curves. Also shown in Figure 8 is the maximum safe forward bias area.

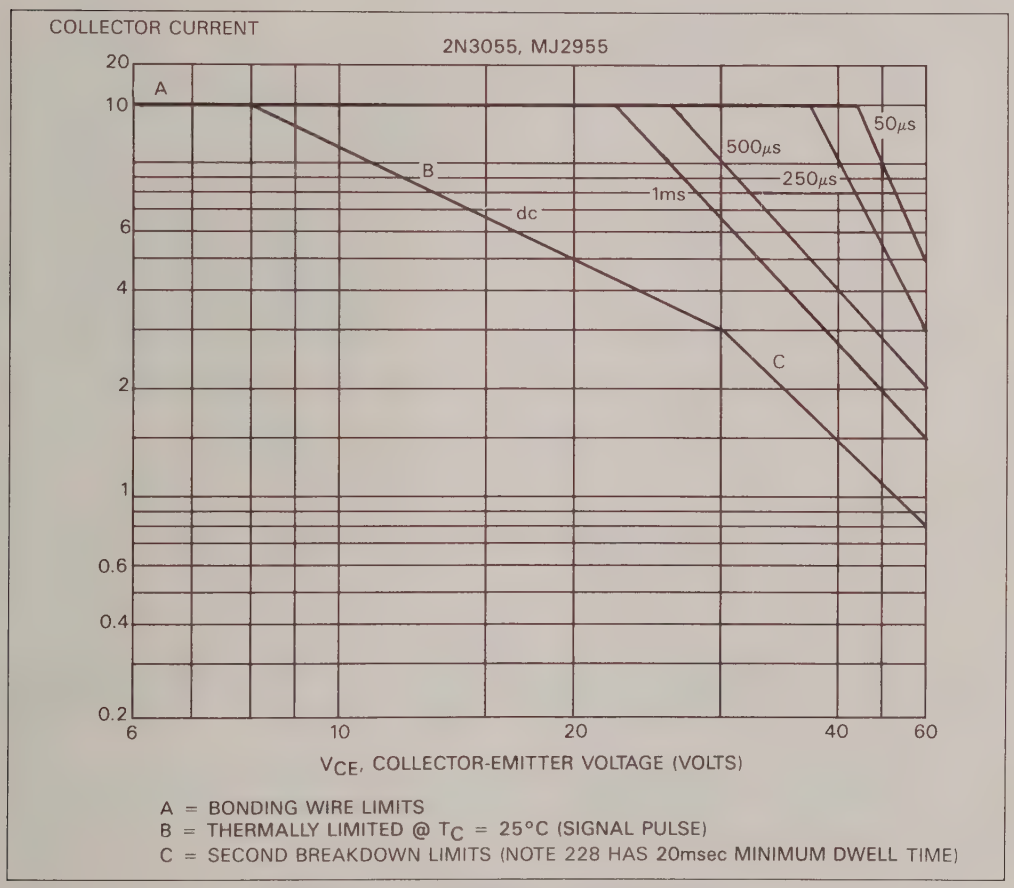


Figure 8. Transistor I_C/V_{CE} Curves

For incoming inspection testing, manual testing may not be cost effective. The configuration shown in Figure 7 may be connected to the IEEE-488 bus and a computer. The Model 228 has a built in IEEE-488 interface that allows the test circuit to be incorporated into the measurement system. Figure 9 shows the configuration with Model 228s connected to a computer over the IEEE-488 bus.

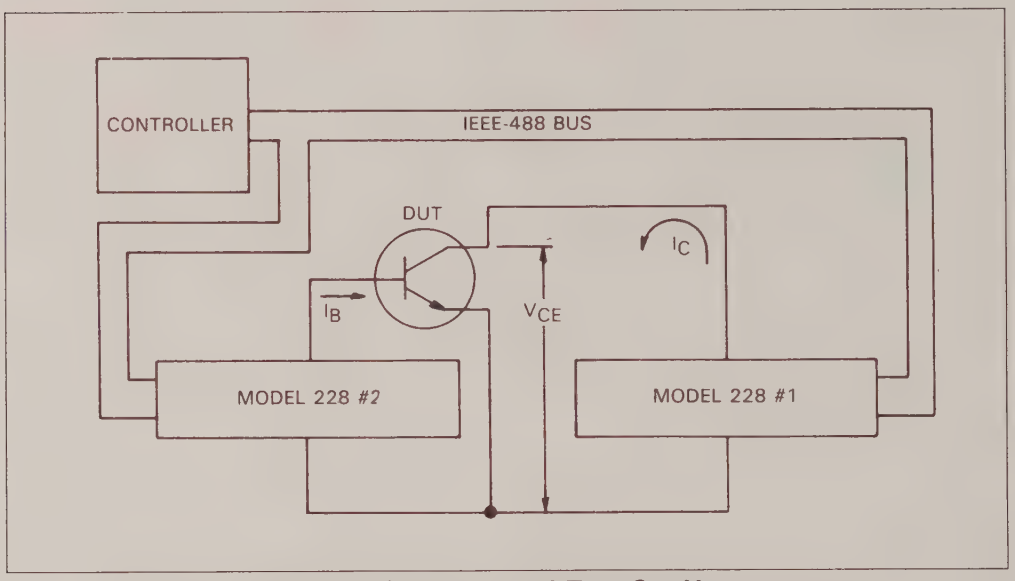


Figure 9. Automated Test Set Up

Using the system configuration, the computer can be programmed to control the testing automatically. The Model 228 responds to IEEE-488 protocol concerning commands and data.

The following program sets two Model 228s to the user selected values. With the configuration shown in Figure 9, the NPN power transistor 2N3055 can be tested for several of its parameters. Some of these tests inlcude:

- Secondary Breakdown: V_{CE} versus I_C
- DC Current Gain: h_{FE} versus I_C @ set V_{CE}
- On Voltage: Voltage versus I_C, V_{BE} plot @ set V_{CE}
- Collector Saturation: V_{CE} versus I_B, I_C plot
- Collector Cut Off: I_C versus V_{BE}, V_{CE} plot

The computer used for the example program is the HP-9816. The program can easily be adapted for voltage as well as current output from the Model 228.

PROGRAM	COMMENTS
10 REMOTE 711	! Set 228 #1 to remote.
20 REMOTE 712	! Set 228 #2 to remote.
30 OUTPUT 2;''K'';	! Clear screen.
40 OUTPUT 711;''F0X''	! Set 228 #1 to standby.
50 OUTPUT 712;''F0X''	! Set 228 #2 to standby.
60 PRINT ''SELECT COLLECTOR CURRENT. EXAMPLE 1 = 1AMP''	
70 INPUT B	! Input current value.
80 OUTPUT 711;''I'';B;''X''	! Set 228 #1 to value selected.
90 OUTPUT 2;''K'';	! Clear screen.
100 PRINT ''SELECT BASE CURRENT. EXAMPLE: .5 = 500MA''	
110 INPUT C	! Input current value.
120 OUTPUT 712;''I'';C;''X''	! Set 228 #2 to value selected.
130 WAIT 3	! Wait 3 seconds.
140 OUTPUT 2;''K'';	! Clear screen.
150 PRINT ''IN THE OPERATE MODE THE MODEL 228 DISPLAYS ACTUAL VALUES.''	
160 PRINT ''NOT THE PROGRAMMED VALUES.''	
170 WAIT 3	! Wait 3 seconds before operate.
180 OUTPUT 711;''F1X''	! Set 228 #1 to operate.
190 OUTPUT 712;''F1X''	! Set 228 #2 to operate.
200 WAIT 3	! Wait 3 seconds.
210 OUTPUT 2;''K'';	! Clear screen.
220 PRINT ''REPEAT TEST? Y = YES N = NO THEN PRESS ENTER''	
230 INPUT A$	! Input command.
240 IF A$=''Y'' THEN 30	! If yes, repeat.
250 IF A$=''N'' THEN 260	! If no, go to line 210.
260 OUTPUT 711;''F0X''	! Set 228 #1 to standby.
270 OUTPUT 712;''F0X''	! Set 228 #2 to standby.
280 OUTPUT 2;''K'';	! Clear screen.
290 PRINT	
300 PRINT ''TURN OFF ALL OF THE TEST EQUIPMENT''	
310 END	

Power Supply Testing

The Model 228 is capable of acting as a source or as an accurate and stable load. Power supplies and batteries can be tested with the Model 228 acting as the load. Controlled charge and discharge of batteries is a good application of the Model 228. The load conditions can be programmed over the IEEE-488 bus or from the front panel. Figure 10 shows the configuration of the Model 228 sinking power from the battery. The battery in the figure is rated at 10V. The Model 228 must be programmed for a voltage of less than 10V to operate in the sink mode. When the voltage of the Model 228 is less than the voltage of the battery, current is drawn from the battery into the Model 228. The COMPLIANCE graph shows that the instrument is operating in the sink mode. The voltage is positive but, the current is being drawn from the battery which shows up on the COMPLIANCE graph as negative current. Discharge will stop when the battery voltage reaches the programmed voltage (see Figure 11).

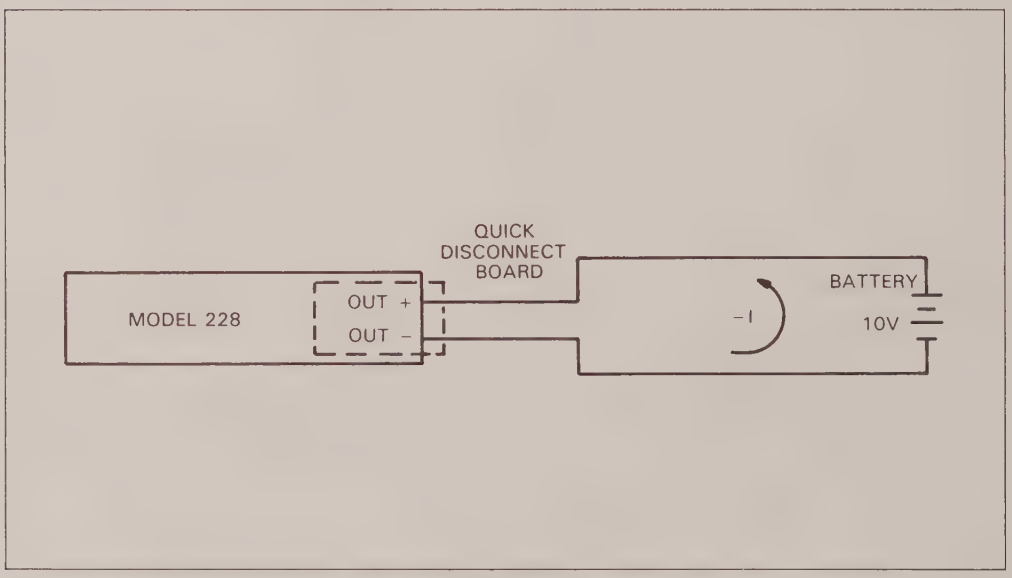


Figure 10. Battery Life Test

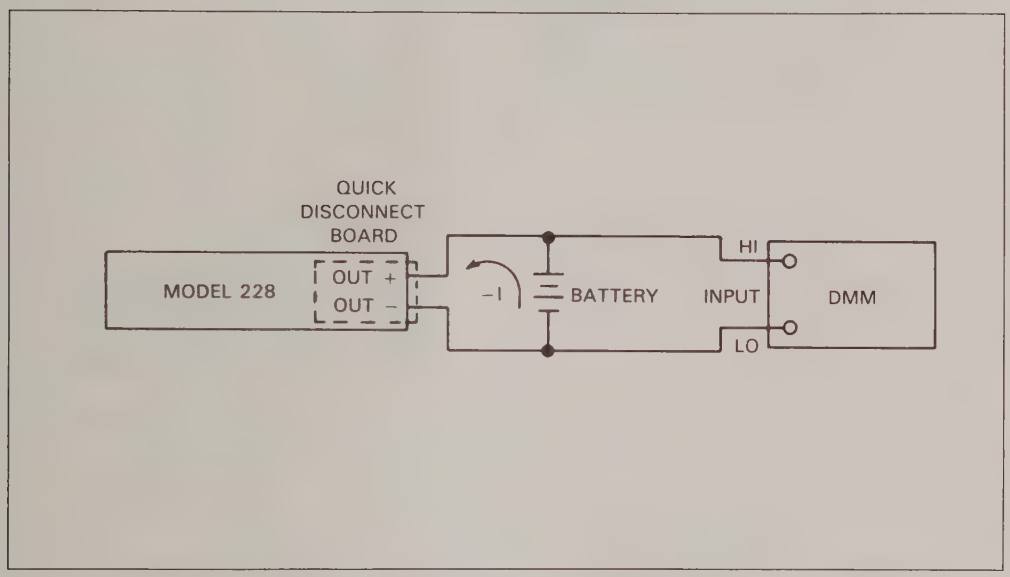


Figure 11. Data Logging Configuration

When using the Model 228 to test power supplies; most power supplies would be damaged if external voltages or currents are forced upon them. Figure 12 is a suggested protection circuit for the external power supply. The two protection diodes in the circuit protect most supplies in the event one of the following situations occur.

1. Incorrect Model 228 polarity.
2. Improper power on sequence (Model 228 before external supply).
3. The Model 228 is programmed for excessive voltage.

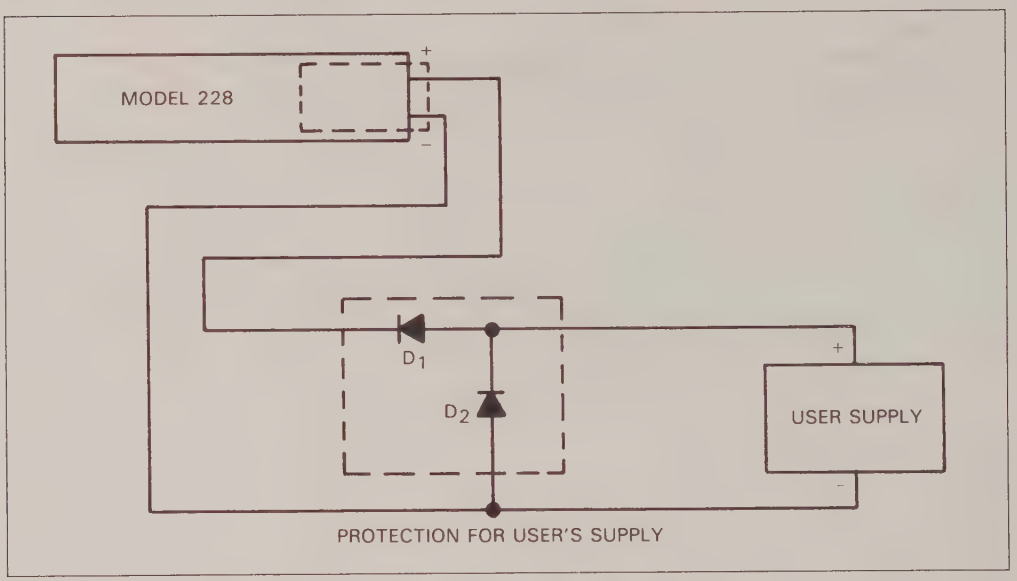


Figure 12. Power Supply Protection Circuit

Model 228 Extended Voltage and Current

The Model 228 has several ranges that can be selected to suit a particular application. The most power a Model 228 can produce is 100W. This level of power can be obtained by 100V at 1A or 10V at 10A. In general, this power is enough for most applications. Sometimes however, a higher voltage or a higher current that is outside of the Model 228 specifications is required. In these situations the Model 228 can be connected to another Model 228 for higher output of voltage or current.

NOTE

Connecting multiple Model 228's in series or parallel does not increase the sink capability. Instead, it increases the voltage or current source capability.

The highest amount of voltage possible from multiple Model 228s is 200V. This is due to the common mode voltage specification of 100V. The common mode voltage of 100V must not be exceeded on either instrument. Figure 13 shows the method of connecting two Model 228s in series to obtain a higher voltage. Figure 14 shows the recommended method of connecting more than two Model 228s in series to obtain a higher voltage. In Figure 14 there are three Model 228s. The voltage obtained is not 300V. The maximum is 200V. For example, on the 10V, 10A range, 30V at 10A can be achieved.

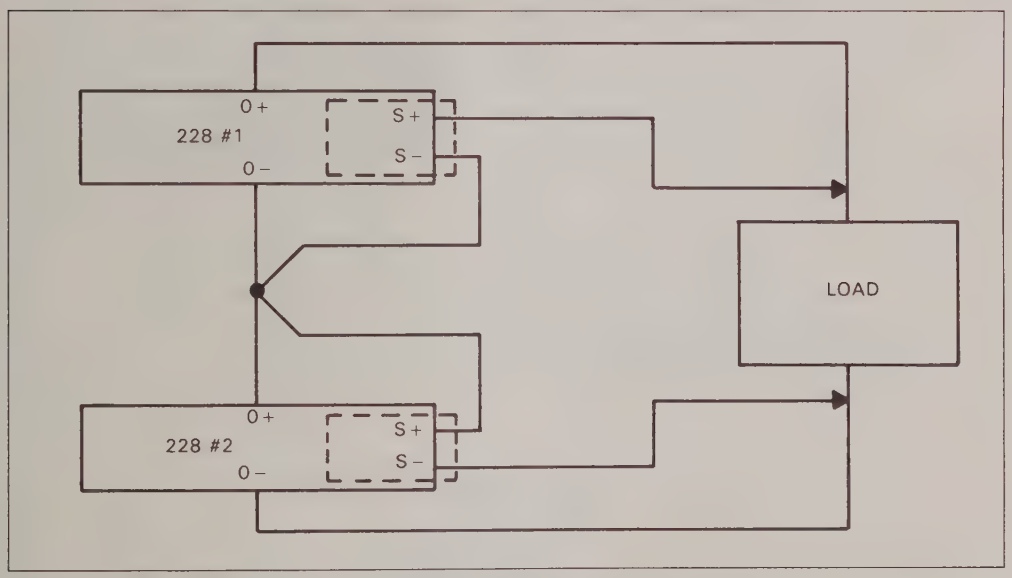


Figure 13. Two Model 228s in Series

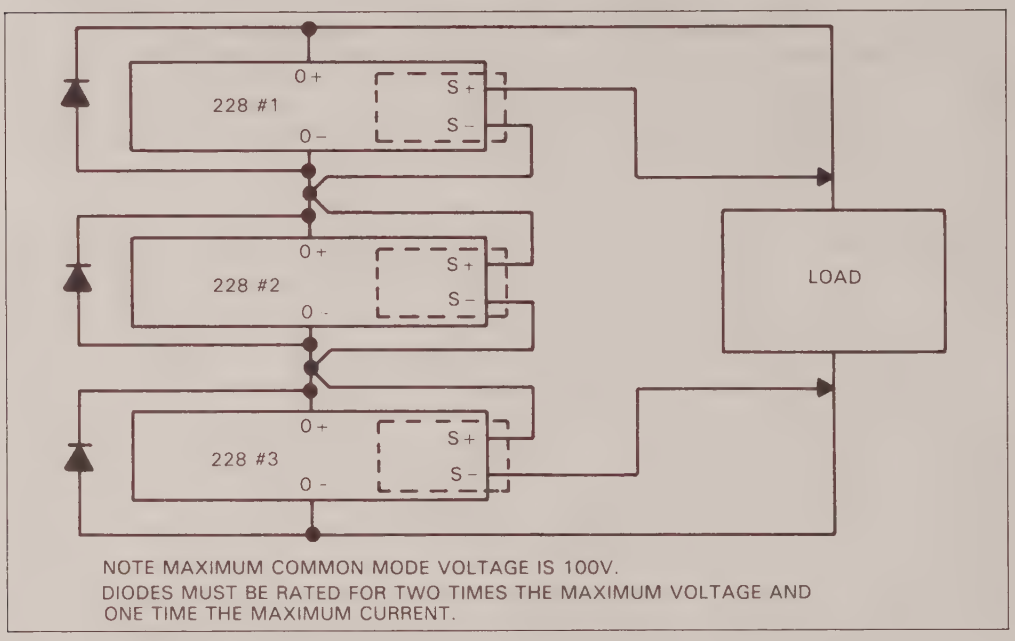


Figure 14. Multiple Model 228s in Series

Higher current can be obtained by connecting multiple Model 228s in parallel. Refer to Figure 15. Two supplies can be connected in parallel for higher current without any additional protection circuitry. If more than two supplies are connected in parallel additional protection circuitry is required as shown in Figure 16. The diodes allow the supplies to output current but not to sink current. In Figures 15 and 16 the supplies are set for remote sense.

The amount of current is limited to the number of supplies connected in parallel. Each Model 228 can deliver up to 10A on the 10V, 10A range. Each additional Model 228 connected in parallel increases current capability another 10A. For example, if three Model 228s are connected in parallel as shown in Figure 16, current capability is increased to 30A. This rating is on the 10V, 10A range. The increase in current capacity applies to all the ranges of the Model 228. For example, the 100V, 1A range is increased to 100V, 3A output.

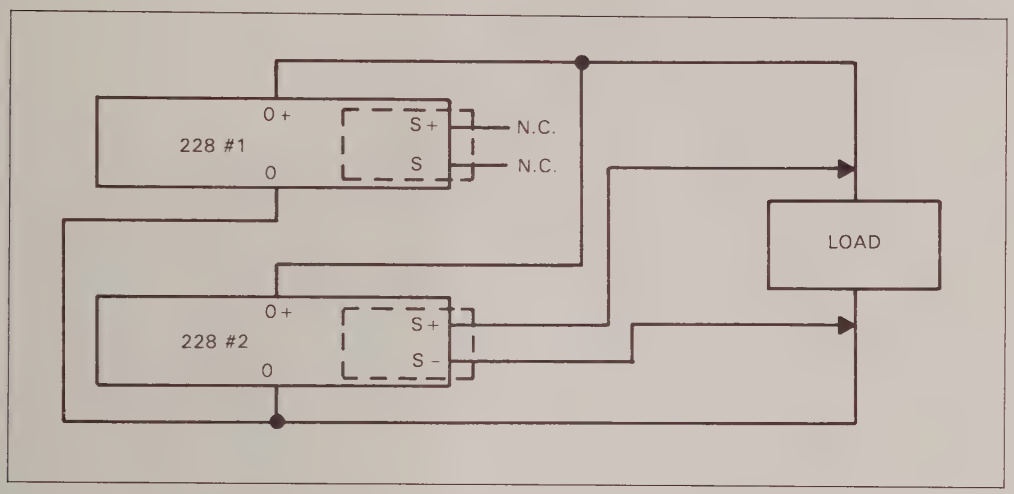


Figure 15. Configuring Two Model 228s for Higher Current

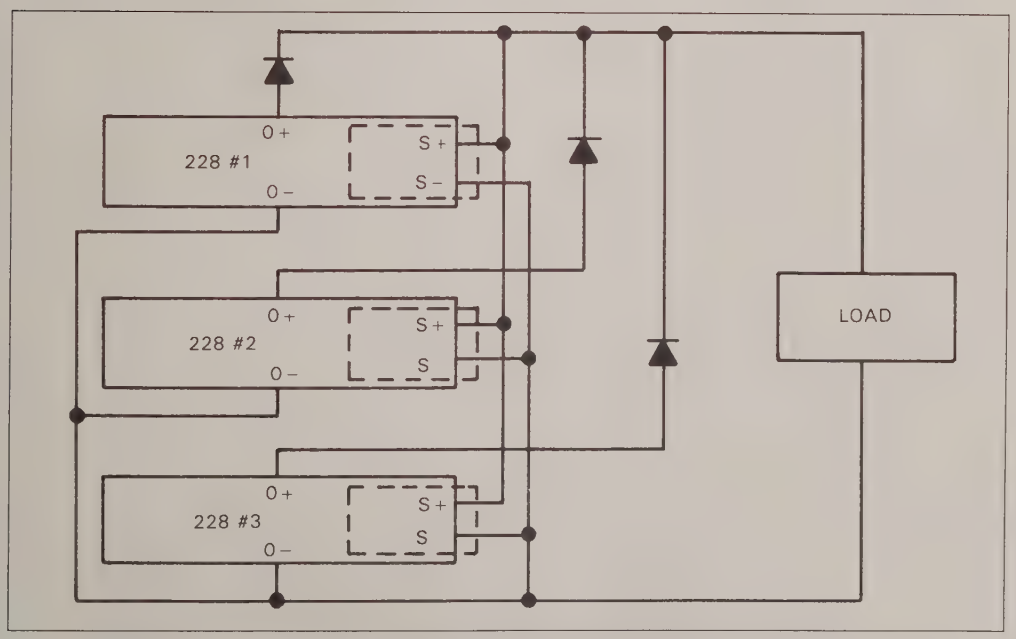


Figure 16. Configuring Three or More Model 228s for Higher Current

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